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THE EFFECTS OF TENSILE PRELOADS ON THE IMPACT RESPONSE OF CARBON/EPOXY LAMINATES

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ABSTRACT

The effects of tensile preloads on the tension-after-impact (TAI) strength of composite laminates of IM7/8551-7 were examined. A failure threshold curve was first determined so the most informative values for preload/impact energy combinations could be determined. The impact tests were instrumented so maximum load of impact, as well as several other parameters could be measured. The elastic response data indicate that as the tensile preload is increased, the maximum load of impact also increases. The damage data show that at low impact energies, the damage/failure is an "all-or-nothing" event but at higher impact energies, a region of preload values exists where the coupons could sustain damage, yet not fail catastrophically.

KEY WORDS: Composites, Impact Resistance, Fracture

1. INTRODUCTION

Many papers have examined the effects of foreign object impact to composites, yet there is not much data that shows the change in these effects when the test coupon is under a state of tensile prestress. Avva (1) has presented a good amount of experimental data. In this study it was shown that tensile preloads had a mild detrimental effect on the tension-after-impact (TAI) strength of quasi-isotropic laminates. The same results were also found when the laminates were used as facesheets for sandwich panels (2).

Sun and Chen (3) performed a finite element analysis of the material response aspect of this problem and found that the tensile preload will tend to increase the maximum force of impact and decrease the duration of contact.

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Park (4) examined the effects of tensile preloads on the damage of many different material types including carbon/epoxy laminates. The assertion is made that the stresses due to the preloading and the impact event can be superimposed to obtain the stress state within the test coupon.

An important concept is that of a "failure threshold curve" (5). This is the line of catastrophic failure on an impact energy versus prestress chart. A "catastrophic failure" is an impact event where the combination of prestress and impact induced stress fracture the specimen resulting in a test sample with zero residual strength.

2. EXPERIMENTAL

2.1 Material The fiber/resin system used in this study was IM7/8551-7 laid-up in a stacking sequence of [0,90,90]. The material was hand laid with an autoclave cure cycle as recommended by the manufacturer.

2.2 Test Specimens Test coupons were cut from the cured panels with dimensions 17.8 cm (7 in.) long (0°- direction) by 7.6 cm (3 in.) wide. Fiberglass tabs 3.8cm (1.5 in.) long and running the width of the specimen were bonded onto the ends of all of the coupons. In order to ensure that a uniform strain was induced into the specimen, three strain gages were placed on the test specimens as shown in figure 1.

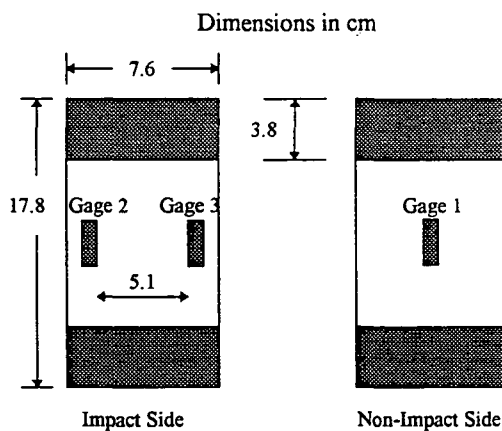


Figure 1. Placement of Stain Gages and Dimensions of Specimens Used.

The gages were monitored during the preloading process and if a deviation greater than 15% occurred between any two gages, the loading was halted and the specimen reloaded to try to obtain a more uniform strain field.

2.3 Tension Preload Device The tensile preloads were applied using a wedge grip fixture operated by a hydraulic piston as shown in figure 2. A load cell was placed between the hydraulic piston and one of the wedge grips to supply a reading of the load being applied to the specimen. The specimen rested on a steel block with a square cutout of 6.35 cm (2.5 in.). A plate with a similar size cutout was placed on top of the specimen and lightly secured to the bottom block via 6 allen screws. This provided a square, semi-

clamped boundary condition. Strain readings were taken at 2.2 kN (500 lb) increments, except in the case of specimens that were loaded above 22 kN (5,000 lbs) where readings were taken every 4.4 kN (1,000 lbs).

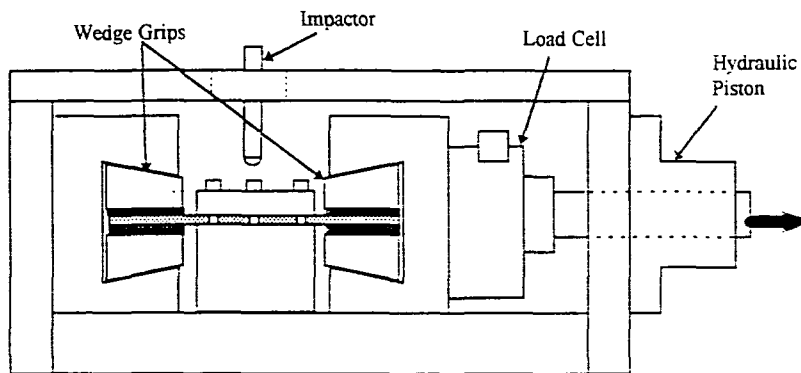


Figure 2. Tensile Preloading Device.

2.4 Impact Testing Instrumented impacting with a Dynatup 830 data acquisition system allowed several impact parameters, including maximum load of impact to be measured for each impact event.

The impactor was a 6.35 mm (.25 in.) diameter tup with a drop weight of 1.2 kg (2.6 lbs). After each impact event, the specimen was carefully removed and inspected for visual damage. If the specimen broke apart after the impact, that event was considered a "catastrophic break" with a residual strength of zero.

3. RESULTS

3.1 Visual Damage The visual damage fell into one of three categories, i) no damage, ii) clearly visible damage and iii) catastrophic failure. There were no specimens that exhibited barely visible damage as is the case when testing coupons without a tensile preload. This is thought to be a result of the increased crack propagation rates induced by the preload in combination with the bi-directional and grouped (i.e. all 90° plies in the center of the laminate) nature of the coupon.

3.2 Maximum Load of Impact The maximum load of impact for all of the tests run, along with the corresponding type of visual damage, is given in figure 3. A cursory observation of these values indicates that at a given impact energy, an increasing preload does give rise to an increased maximum load of impact. For example, impact energies in the range of .7 J (.52 ft-lbs) show that as the preload increases from 6.7 kN (1,500 lbs) (run 5A) to 31.4 kN (7,050 lbs) (run 23), the maximum load of impact increases from 499 N (112 lbs) to 610 N (137 lbs). Also, at impact energies of about 1.4 J (1.0 ft-lbs), as the preload goes from 3.9 kN (875 lbs) to 13.4 kN (3,000 lbs) the maximum load of impact increases from 784 N (176 lbs) to 832 N (187 lbs) (runs 3A and 6A). As damage occurs in the specimens, this trend disappears. When damage occurs to the test coupon, the

impacting load is "relieved" due to the loss in stiffness of the coupon. This lowering of maximum load is quite evident on the specimens that failed catastrophically.

Specimen #	Preload (kN)	Impact Energy (J)	Maximum Load of Impact (N)	Visual Damage
1A	13.4	.46	421.1	No
2A	20.0	.69	554.5	No
3A	3.9	1.41	784.0	No
4A	22.8	1.37	813.1	Catastrophic
5A	6.7	.69	499.4	No
6A	13.4	1.38	832.1	No
7A	13.4	2.33	870.8	Yes
8A	20.0	2.03	955.4	Yes
9A	6.7	2.07	996.7	No
1	31.2	.35	419.6	No
2	31.2	.69	586.1	No
3	31.2	1.06	692.4	Catastrophic
4	26.7	1.07	715.1	Catastrophic
5	18.0	2.35	994.6	Catastrophic
6	33.4	.64	525.1	Catastrophic
7	22.3	2.03	757.4	Catastrophic
8	20.0	1.72	872.6	Catastrophic
9	17.7	1.38	789.4	Yes
10	24.4	.68	499.7	No
11	0	2.93	1,101.8	Yes
12	0	2.01	851.7	Yes
13	24.5	1.02	727.6	No
14	13.7	1.59	886.0	Yes
15	13.4	1.83	925.6	Yes
16	2.8	2.58	1,129.0	No
17	9.0	2.35	1,102.3	No
18	20.1	2.35	688.9	Catastrophic
19	11.1	2.03	995.9	Yes
20	11.2	2.60	854.0	Yes
21	8.9	2.67	1,054.7	Yes
22	20.1	2.74	902.0	Catastrophic
23	31.4	.68	610.1	No
24	20.4	1.91	475.7	Yes
25	33.5	.62	No Data	Catastrophic
26	27.1	.89	150.9	No
27	20.0	1.68	402.6	Yes
28	13.4	1.72	596.7	No
29	6.7	2.68	864.2	Yes
30	25.7	1.08	303.5	Catastrophic
31	24.7	1.06	327.1	Yes
32	30.4	.92	93.9	Catastrophic
33	6.8	2.68	785.0	Yes
34	4.5	2.68	952.6	Yes

Figure 3. Specimen Settings and Maximum Load of Impact.

3.3 Failure Threshold Curve The specimen damage at each preload/impact energy combination tested was classified as non-visible, visible or catastrophic. A plot of the results is presented in figure 4.

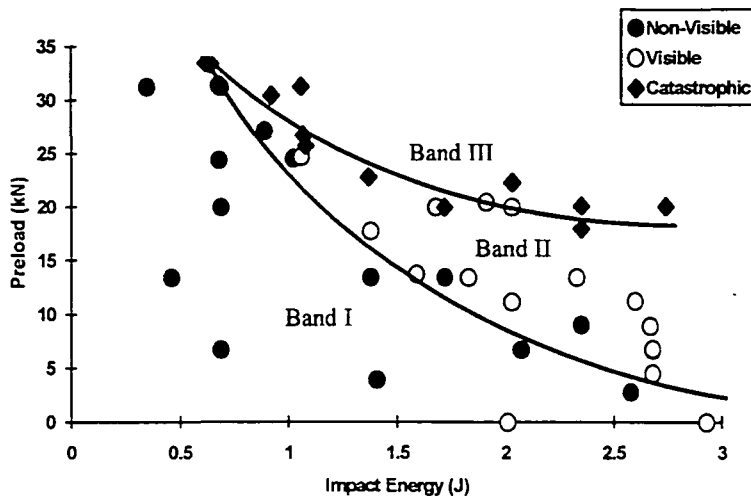


Figure 4. Failure Threshold Curve for Specimens tested.

The three types of visual damage are well defined in bands labeled I, II and III. Band I is the preload/impact energy combinations which produce no visible damage, band II consists of the preload/impact energy values that produce clearly visible damage, and band III are the preload/impact energy values that cause catastrophic failure of the specimen. Note that if the specimens have no preload applied to them, then visual damage will occur even though this is in region I. This is due to the change in boundary conditions between a specimen with no initial load and a specimen with a slight preload. If a specimen has no preload applied to it, it will belong to a different family than those specimens with even the slightest preload. This must be taken into consideration when analyzing the data presented.

As the value of the preloads decreases, the range of impact energies that produce visible damage increases (i.e. band II becomes larger). At high preloads, the specimen is near its undamaged breaking stress and any induced damage will be more than enough to completely fracture the specimen. As the preload decreases the specimen is able to sustain damage without fracturing. At the extreme lower boundary of this case (band II), the preload will not be high enough to fracture the specimen, even when the tup completely penetrates the specimen.

3.4 Residual Tensile Strength The residual tensile strength of the specimens that sustained no visible damage was extremely consistent at a value of approximately 670 MPa (97,000 PSI). This is not an unexpected result since a decrease in tensile strength will only occur if fibers are broken, or if there is gross matrix damage, both of which would be visible. For the specimens that did sustain visual damage, the residual tensile strength was also fairly constant at 475 MPa (69,000 PSI). The exceptions to this were one specimen in the upper part of band II having a lower residual tensile strength and three specimens at the highest impact energy levels (with the lowest preloads) in band II having higher tensile strength values. These results are shown in figure 5. This demonstrates that the higher preloads can enhance the propagation of tensile strength degrading damage through the specimen more so than the higher impact energies.

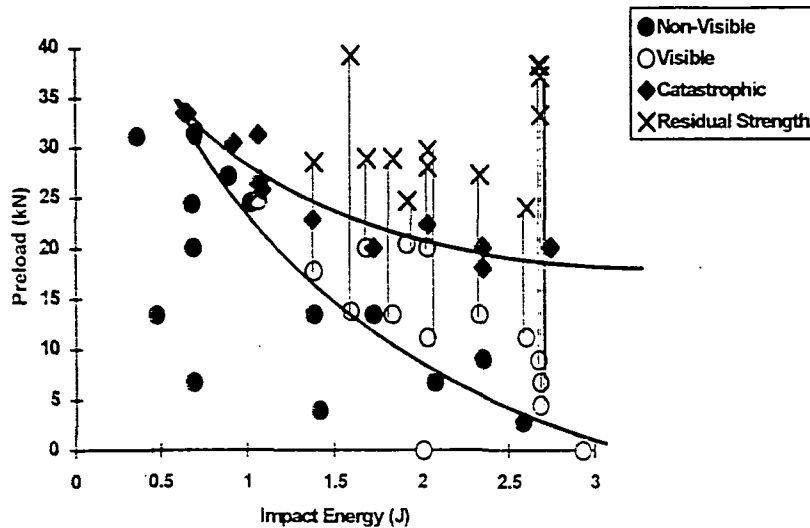


Figure 5. Failure Threshold Curve With Residual Strengths of Damaged Specimens.

4. CONCLUSIONS

The effect of tensile preloads on the elastic response (no damage) of bi-directional IM7/8551-7 carbon/epoxy is to increase the maximum load of impact due to the increased bending stiffness induced by the preload.

Tensile preloads tend to cause the composite samples to experience either a complete fracture or no damage at low impact energies. At higher impact energies, a region exists where the impact energy/preload combination will cause visible, but not catastrophic, damage. If visible damage occurs on the coupon, the residual strength will be lower, except if the coupon was impacted at a relatively high impact energy and low tensile preload. The tensile preload can enhance the propagation of matrix cracking and thus the gross matrix damage that can cause reductions in residual strength.

5. REFERENCES

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